Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

Observability of Microgrid Operations by the California Independent System Operator

Prepared for: California Energy Commission

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PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Observability of Microgrid Operations by the California Independent System Operator is a deliverable for the California Energy Commission contract number 500-10-043 conducted by the University of California, San Diego. The information from this project contributes to PIER's Renewable Energy Technologies Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

It is likely that microgrids will become more prevalent within the larger power grid and network. It is therefore important to raise the situational awareness and understanding of the Regional Transmission Organization/Independent System Operator (RTO/ISO) of distributed energy resources (DER). DERs are often "behind the meter," where they will not even appear as supply, but as load reductions. With greater penetration of DERs observability, dispatchability, and permitted autonomous actions by DERs must be established. One approach to addressing these issues is to organize the DERs into structures that can be more easily characterized and understood, such as a microgrid. Microgrids represent assimilation of loads and generation and can both supply generation services as a net resource or also at times be a net load. Microgrids also will likely be able to bid into California Independent System Operator (CAISO) markets and provide energy, capacity and other ancillary services. And just like any other resource it will be important for CAISO to have communications and clarity about the operation of these resources, to ensure CAISO area reliability and resource adequacy. The Univerisity of California, San Diego (UCSD) has been working with the CAISO to provide observability of microgrid operations to better understand how microgrids may interact with the larger CAISO system and markets in the future. UCSD as part of task 4.1 of the CEC contract 500-10-043 has developed this report to describe the results of this collaborative effort for CAISO monitoring of UCSD's microgrid.

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EXECUTIVE SUMMARY

UCSD has one the largest (42 MW) and most automated microgrids, a large amount of renewable resources (5.8 MW) and the most energy storage of any microgrid in the United States. UCSD has provided direct access and observational capability of the UCSD microgrid to CAISO. This unique observability allows CAISO to better understand how microgrids operate and how they may interact and participate in CAISO energy markets in the future.

With the objective of learning more about potential CAISO market participation with existing and potential microgrid capability, UCSD engaged with Olivine Inc. to participate in the CAISO Fall 2013 market simulation. Within the UCSD microgrid capability, two resource types were created and modeled in the CAISO market test environment for use during the simulation. The simulation itself was conducted to test new market features that were scheduled for deployment to the production market and included a full representation of system-wide activity and resource participation. This provided an opportunity to learn about the potential exercise of resource capability while simultaneously participating in the CAISO market and maintaining their primary function.

The two resources, one which represented a behind the meter demand response and the other a bi-directional storage resource, were bid into the CAISO market test environment over a number of weeks for a variety of products that included economic energy and frequency regulation. The bids successfully cleared the markets and returned data sets that can be used for further analysis as well as three days of "bid to bill" data that provide insight into the full financial scope of market participation. While the prices returned from the market simulation cannot be used to project the potential revenue for wholesale market participation, the underlying data provides a framework for further analysis utilizing production prices. Perhaps of most use, the data returned on the bi-directional storage resource participating in frequency regulation, provides insight into how storage capability with the primary purpose of supporting photovoltaic (PV) would be dispatched by the CAISO.

CHAPTER 1
INTRODUCTION

The UCSD and California ISO are working together to investigate how microgrids could integrate with the electric power grid and participate in the ISO wholesale electricity markets as flexible energy resources. Flexible energy resources are resources that can respond in ways that help mitigate many of the operational challenges that we expect to see as a result of greater amounts of intermittent and variable renewable generation connecting to the grid to meet the 2020 33% Renewables Portfolio Standard (RPS) target in California. In general, flexible resources are resources that can:

- React quickly and meet expected operating levels
- Sustain upward or downward ramp
- Start and stop multiple times per day
- Respond for a defined period of time
- Change ramp directions quickly
- Start with short notice from a zero or low-electricity operating level
- Accurately forecast operating capability

For microgrids to be effective grid resources, participation protocols and procedures need to be understood and further developed by the California ISO and microgrid developers to ensure reliable and efficient operation of microgrids within the ISO control area. Microgrids offer an alternative architecture to the conventional large scale interconnected network with central power plant dispatch. Potential benefits of microgrids include increased reliability, lower operational costs on a local basis, and more efficient use of distributed renewable generation.

CHAPTER 2:
Microgrid Operations

2.1 Microgrid Observability Test With The CAISO

As part of this project UCSD provided the CAISO access to its OSIsoft PI System to monitor microgrid operations. Integrated into the OSI PI system is the Power Analytics Paladin system which serves as analytics for the microgrid. Power Analytics is an associated power system model that dynamically recalculates critical power and energy information based on the changing conditions of the microgrid. The combination of capabilities of the OSI Pi server and Power Analytics provide detailed information with the purpose to enable CAISO to achieve a Deep Situational Awareness of the performance of UCSD's distributed energy resources particularly during demand responses called by CAISO and Critical Peak Pricing called by San Diego Gas & Electric (SDG&E). Through a Remote Terminal Server, and in compliance with CAISO's and UCSD security requirements, CAISO has direct access to the UCSD PI System. CAISO is able to utilize PI Client Software and Analytics tools to visualize and analyze both real-time and historical time-series data and context from the UCSD PI system. To date the UCSD PI System acquires and stores the following data streams from the UCSD Microgrid, at speeds as fast as 60hz.

PI 107,860

PMU 1096

East Campus Substation Server 661

The Power Analytics model writes 17,326 tags back to the PI server. An example of the current tag-list and frequency is provided in Attachment A.

If desired, CAISO could establish a secure Cloud Connection between the UCSD PI System and CAISO's PI System(s). This Cloud Connection would provide CAISO Analysts with access to highly granular historical data and context within the CAISO PI Systems to enable correlation and other analytics on the performance of the UCSD Microgrid in conjunction with the Transmission/Distribution grid "outside the fence".

In addition, the UCSD PI System is configurable to provide near real-time notifications to CAISO upon observed or calculated events from the UCSD Microgrid. All of these observations, calculations, and notifications are at any metered granularity of distributed energy resources including energy storage that are not typically observable since they are "behind" the utility meter.

The high performance of the OSI PI environment combined with the analytics and visualization of Power Analytics Paladin system convey status and performance at a glance and provide CAISO and any authorized user the ability to view what is relevant and appropriate. The following Figures 1- 6 show the user screens that are developed by Power Analytics Paladin control system that are available to the CAISO.

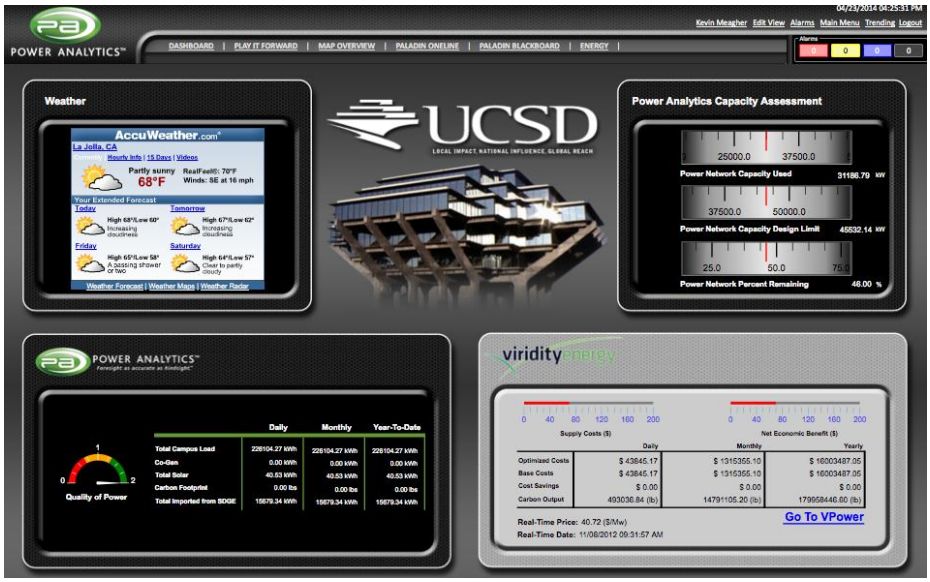

Figure 1 Main Dashboard - Default login and overview of the UCSD Campus

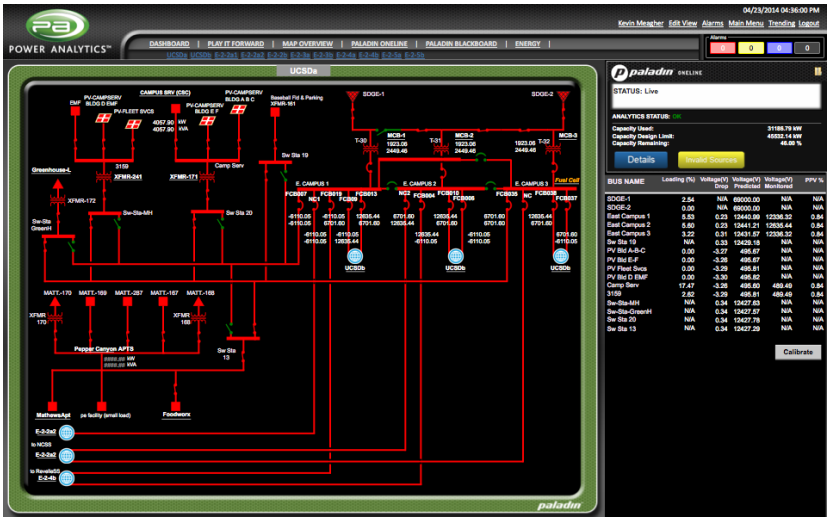

Figure 2 Campus Power Network – Electrical oneline of the campus animated to show status of the network interspersed with critical meter values from OSI PI. Predicted values are compared to actual values at key locations.

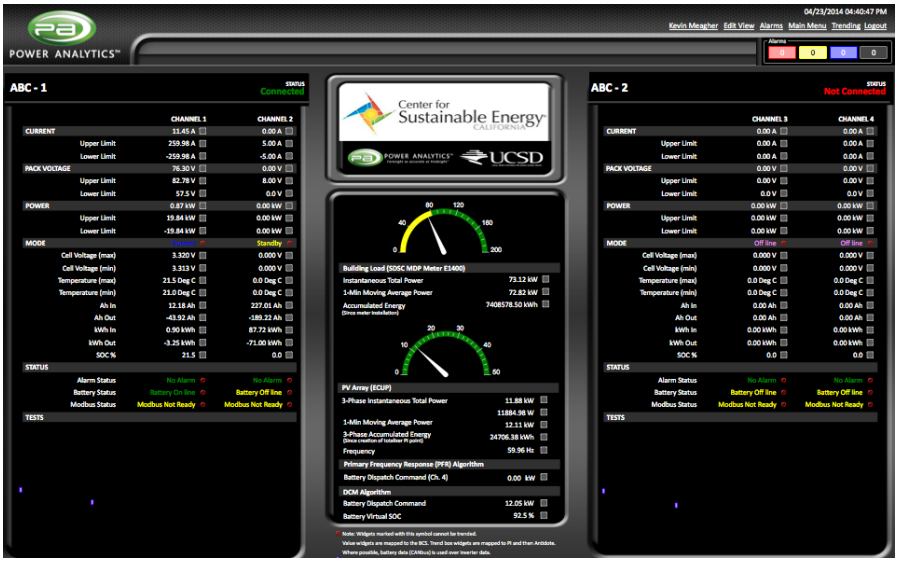

Figure 3. Second Life Battery Dashboard - Integrating used EV energy storage with photo voltaic performance.

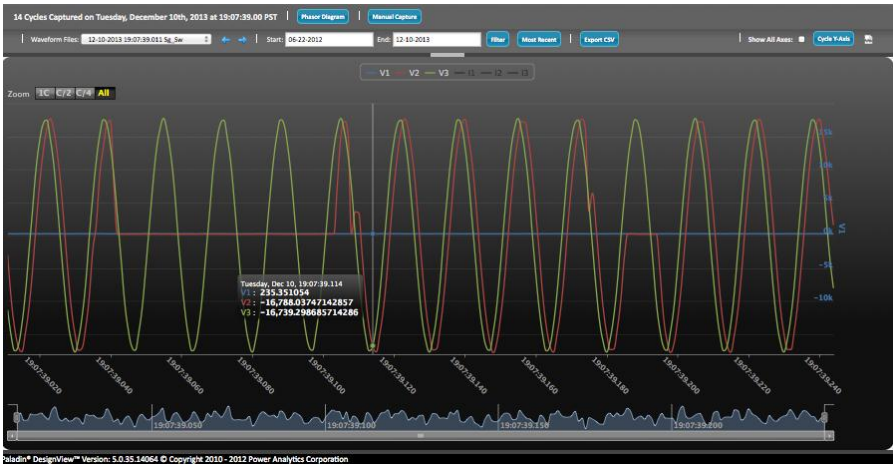

Figure 4 High resolution wave form capture at the ouput of the 2.8 megawatt fuel cell showing millisecond resolution.

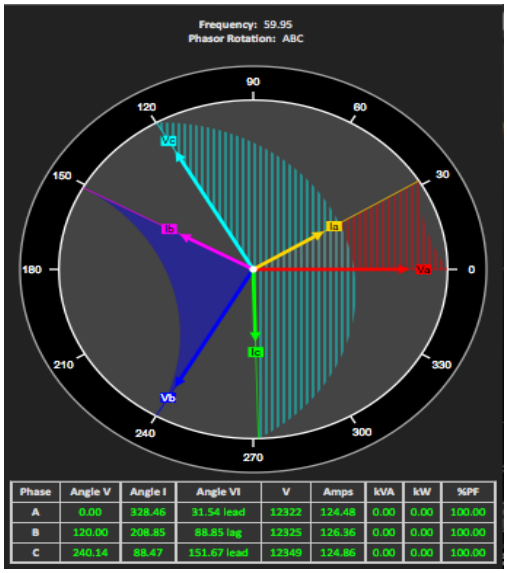

Figure 5 Associated real time phasor diagram of the same fuel cell output

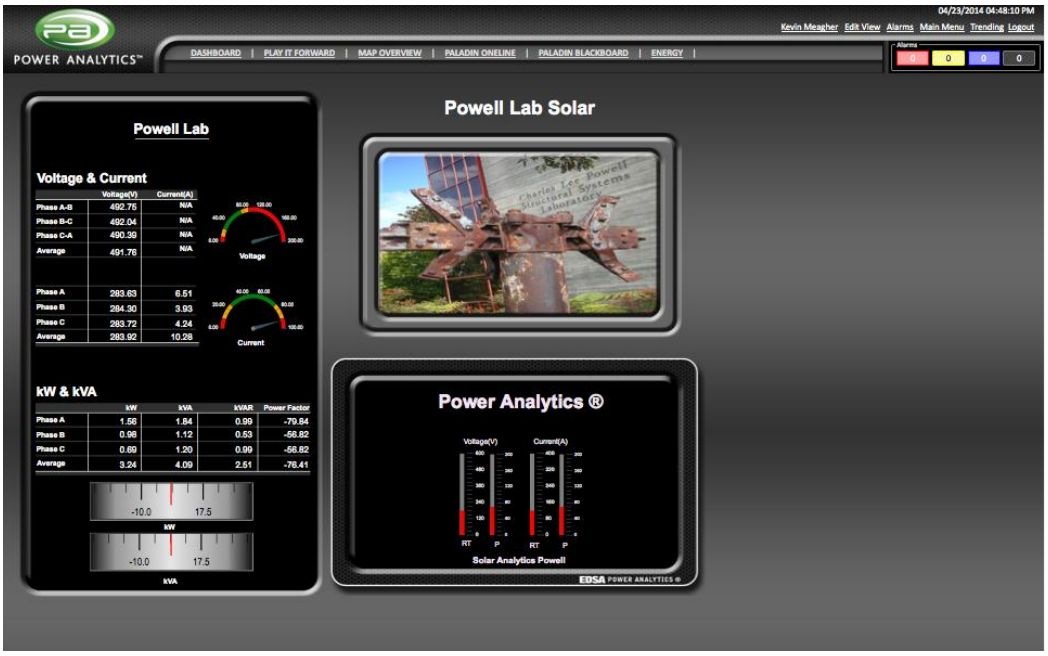

Figure 6 Real time and predicted solar output from one of the solar locations on the campus.

2.2 Interconnection and Planing Requirements for Microgrids and the CAISO

The CAISO and UCSD have discussed how microgrids might integrate with the CAISO larger grid system, and the planning and interconnection requirements that may be needed for microgrids to interconnect and operate reliabily and efficiently. The electrical grid can be broken into two levels based on its architecture and voltage. These two levels consist of the transmission system and the distribution system. The transmission system transfers the bulk of electrical energy at high voltages from generating power plants to electrical substations. Energy is then distributed to end use customers on the distribution system at lower voltages. The level at which the microgrid resource physically interconnects to the grid is extremely important in terms of interconnection rules and policies. Transmission level interconnection is managed by the ISO under federal jurisdiction. Distribution level interconnection is managed by the Utility Distribution Company (UDC) which is under the jurisdiction of the California Public Utilities Commission (CPUC). Defining the electrical footprint of the microgrid and determining where the points of interconnection exist is a critical step. At UCSD there is one point of interconnection of the microgrid to the grid. This is valuable both in terms of providing islanding capability as well as being able to measure and monitor microgrid resource performance independent of neighboring interconnected resources. If the resource is connected at distribution level voltages and wishes to participate in the ISO wholesale energy market, the resource must first satisfy the Utility Distribution Company (UDC) interconnection requirements and obtain an appropriate interconnection agreement, normally called a wholesale distribution access tariff (WDAT). The interconnection process and agreements work to ensure that either

the UDC or the ISO (and sometimes both) perform the necessary studies that maintain grid safety and reliability. If the individual microgrid resources have already interconnected with the grid under distribution interconnection studies, the creation of a microgrid will likely trigger a new interconnection study based on the intended operation of the microgrid. As a wholesale resource, the microgrid could be managed to control generation or load based on a wholesale pricing. No longer does generation act primarily as a load modifier, but in conjunction with load management, may allow the microgrid to define a new level of generation export. Because loads of the microgrid are now a market commodity and will be managed based on price, consideration will need to be made to the load serving entity (LSE) that is responsible for procuring sufficient load in the service area within which the microgrid resides. Over or under procurement of load by the LSE will have financial ramifications that will need to be resolved between the LSE, microgrid resource owner, and perhaps other entities.

2.3 CAISO Market Simulation of the UCSD Microgrid

As part of the effort to understand how microgrids with high PV penetration would operate in within a RTO/ISO, UCSD completed a market simulation exercise with the CAISO.

UCSD is tracking the development of new CAISOwholesale products and other opportunities for integrating our microgrid. PV high penetration in a microgrid setting are complemented by battery storage that provides smoothing of the diurnal cycling and intermittent nature PV. To the extent that complementary storage has capability beyond the smoothing needs, it can be optimized as a wholesale market resource depending on the resource models and products offered. The intent of this effort is to participate in CAISO market simulations to explore market integration opportunities.

The CAISO is developing new markets for wholesale products and other California opportunities for integrating their Microgrid as well as informing tasks identified in the Department of Energy (DOE) PV High Penetration projects.

UCSD's stated objectives were to:

- Observe various market participation options for Microgrid capabilities with both Proxy Demand Resource (PDR) and Non Generator Resource (NGR) including both NGR options, Regulation Energy Management (REM) and Non-REM.
- Obtain a "clean" AGC data set for NGR operating in REM option for Frequency Regulation participation.
- Obtain "Bid to Bill" data for various products on both resource types.

To fulfill these objectives, UCSD participated in CAISO market simulations. CAISO operates these simulations on a periodic basis to test the deployment of new market features. Market simulations utilize the Market and Performance Stage (MAP Stage) test environment and typically run bid to bill scenarios to demonstrate the full integration of the new feature prior to release to production. While the Fall 2013 market simulation was not specifically testing specific features associated with microgrids, demand response or energy storage it provided an opportunity to create pseudo-resources to best represent

UCSD microgrid market capabilities and see those resources in a near production environment from bid to bill. Participation in the market simulation provided an opportunity learn more about how UCSD microgird and (virtual power plant (VPP) market capabilities could interface in the market without the risk and the expense of participation in the production market.

The creation of the NGRs required inclusion in the full network model build to be used in the market simulation environment. CAISO personnel outside of the modeling group assisted in development of NGR market models for UCSD for the market simulation. Similarly the CAISO assisted UCSD and its consultant to develop the Proxy Demand Resource Model (PDR) that was placed into the market simulation. The market simulation of the UCSD microgrid was conducted during the months of September through October of year 2013.

Results did provide a number of data points supporting basic market familiarity and that begins to inform the potential of market participation. In particular, the test system outages and the loss of the NGR resource when the system database was truncated returned limited data for the NGR in the Non-REM configuration[1]. Further, because the bid to bill days were run in three successive days, there is not a great deal of variety on those days. The regulation test on the LJOLLA_6_NGR1 resource was completed successfully on Thursday Sep 12 when it ran on a simulated AGC signal and showed similar patterns as other automated generation control (AGC) scenarios observed in previous market simulations.

2.4 Frequency Regulation Test of Microgrid

Results from the market simulation frequency regulation test provide insight into how a energy storage resource might operate in the market when providing frequency regulation. Figure 1 shows a representative example of regulation dispatch during the period when the CAISO operated the scenario. The AGC line show dispatch within the discharge and charge range of the resource while the green field shows how the result of the 50% rule under the Regulation Energy Management (REM) option maintained the State of Charge near the midpoint of the registered storage capacity of 20 MW.

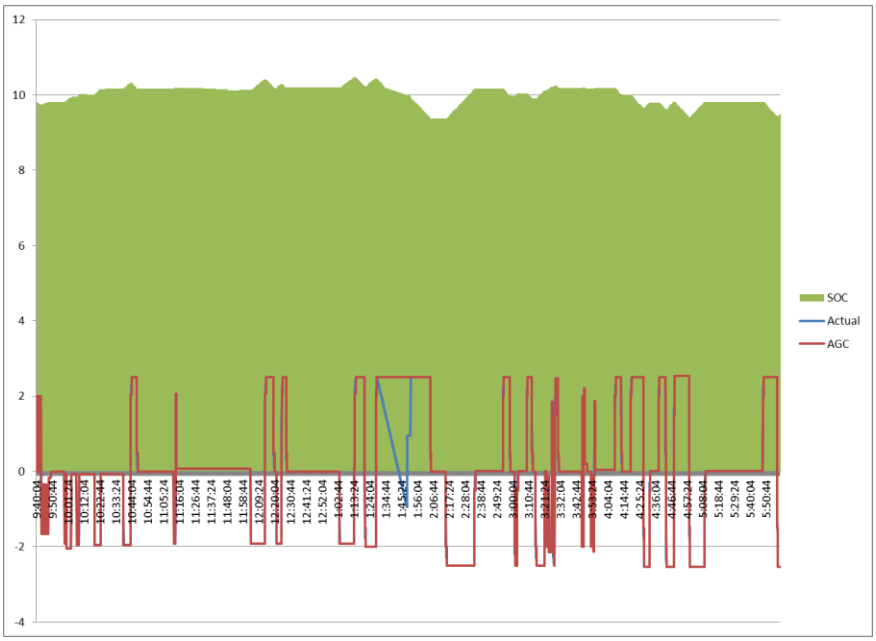

Figure 1 Regulation Energy Management Simulation

CHAPTER 3:
SUMMARY AND CONCLUSIONS

The CAISO has had access to the UCSD real time operations and behind the meter resources through Power Analytic's Paladin system, and has gained valuable insight and information on how micgrogrids operate and how they may participate as resoureces in the future. The ability to control behind the meter energy resources on the microgrid and the integration of real-time analytics of the microgrid were essential to the analysis of energy information and UCSD's ability to respond to DR requests. UCSD and the CAISO need to work on this more to better define how this data can be used to improve overall grid operations.

It is anticipated that additional tests of market participation and data exchange will take place in the future to demonstrate the validity of microgrids and the potential enhancement that they may provide to overall grid operations.

The results of the market simulation did provide a number of data points supporting basic market familiarity and the potential of market participation. The regulation test of the UCSD NGR resource was completed successfully when it ran on a simulated AGC signal and showed similar patterns as other AGC scenarios observed in previous market simulations.

Despite the shortened market simulation and the lack of data for all potential products and resources, the data returned can be used as a starting point for further analysis and multiple simulated scenarios can be developed and executed in the Power Analytic's model. In particular, the two examples of applying production prices to market simulation results provides a roadmap for the development of further scenarios and extension of UCSD's

microgrid capability. Even without the support of a market simulation, an analysis of storage resource to support high penetration PV and its sizing would define the quantities and timing of availability for market participation. UCSD participation in real time markets would be a valuable next step, to gain more valuable information on how microgrids will interact with the CAISO.

Use of the residual storage capability and its value in the wholesale market as either a DR resource or bi-directional NGR can be evaluated by pairing forecast MW quantities with production price data available on the CAISO website. For the purposes of determining frequency regulation revenue potential for a bi-directional NGR utilizing the REM option energy settlement could be ignored since it is difficult to forecast energy quantities and it is not unreasonable to assume energy neutrality over the long run.

Attachment A

Examples of Asset Framework Structure for PI Tags, and PI Displays

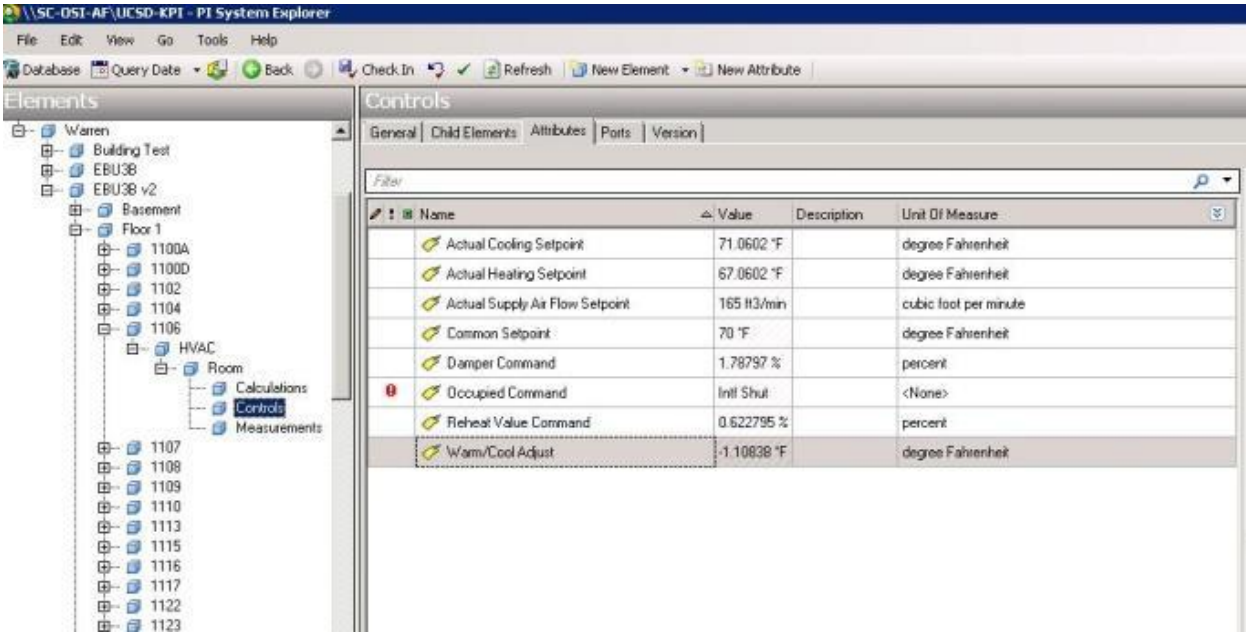

Figure A-1 PI Asset heiarchial tag structure

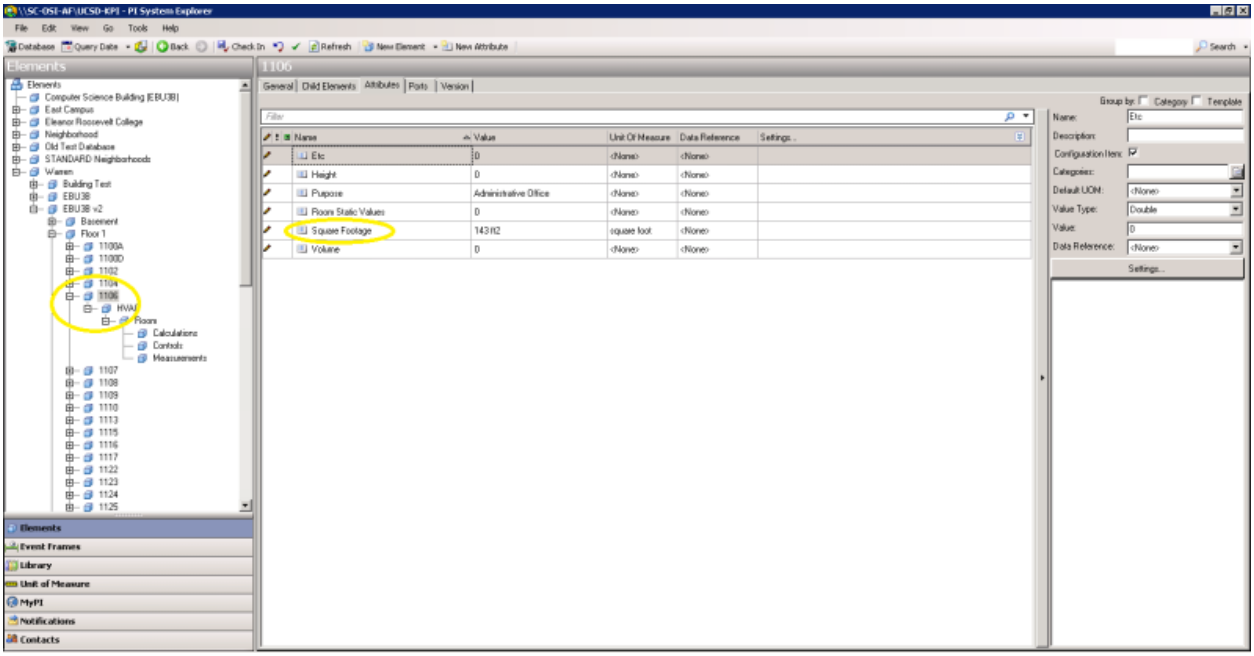

Figure A-2 Example PI Asset Structure

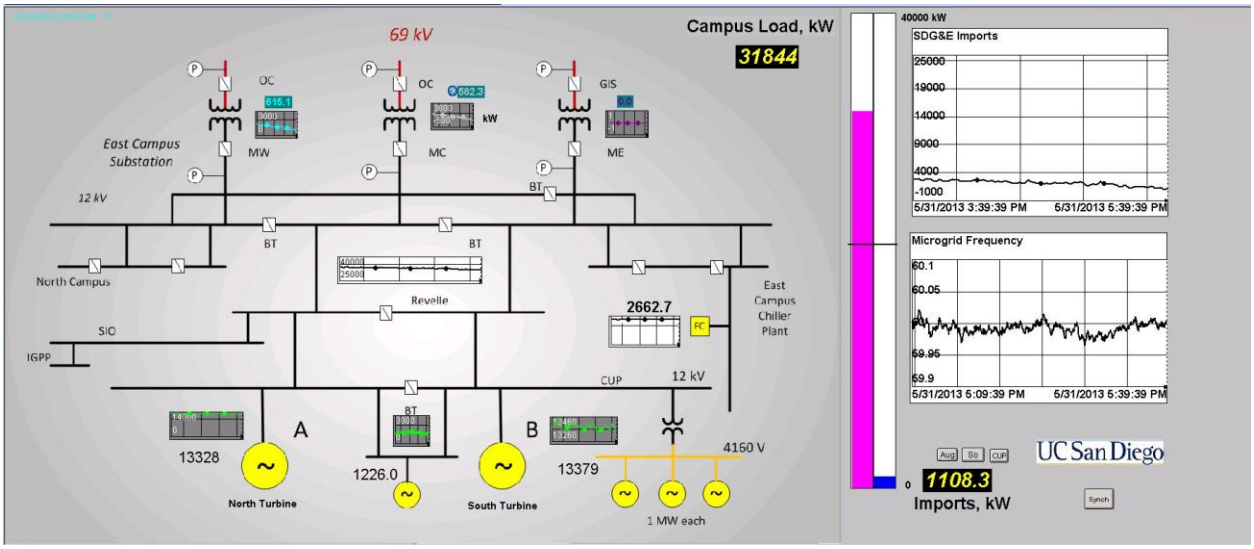

Figure A-3 PI Top Level Real Time Microgrid Operation Display

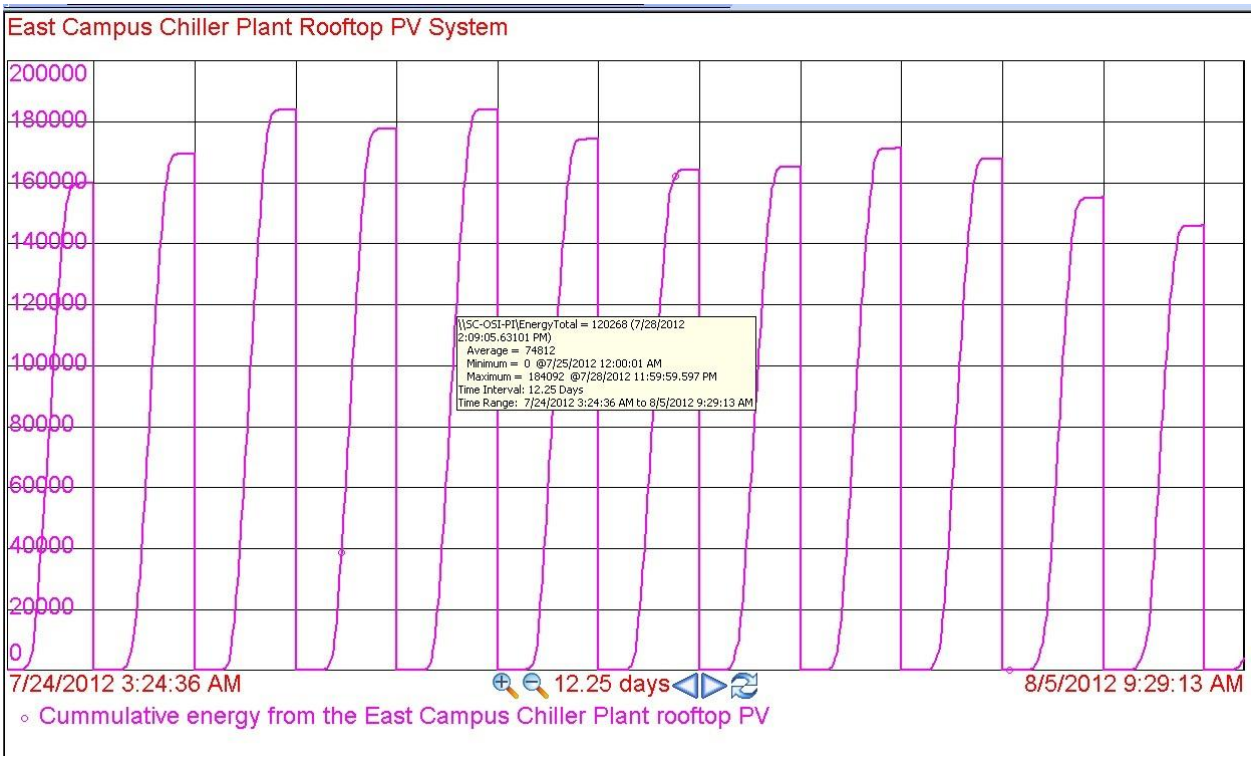

Figure A-4 PI Display of Roof Top PV Production